# HYPERSPECTRAL MEASUREMENTS OF ROCKS AND SOILS IN CENTRAL SREDNOGORIE

*Denitsa Borisova[1], Banush Banushev[2], Hristo Nikolov[1], Roumen Nedkov [1], Daniela Avetisyan[1]*

*[1]Space Research and Technology Institute, Bulgarian Academy of Sciences /SRTI-BAS/, 1113 Sofia; dborisova@stil.bas.bg*
*[2]University of Mining and Geology "St. Ivan Rilski", 1700 Sofia; banushev@mgu.bg*

ABSTRACT. Remote sensing is the technique of acquiring, processing, and interpreting images and multi channels spectral data, acquired from optical imager sensors mounted on aircraft and satellite platforms recording the interaction between investigated objects and electromagnetic energy. Remote sensing application in Earth observation begins with the design and development of equipment for carrying out research of the monitored objects remotely and without disturbing their integrity. Ground-truth data in Earth observation of the environment and in the remote sensing investigations are very important. In this work, remote sensing images are used for mineral exploration in different applications for mapping geology and recognizing soils and rocks by their spectral signatures. We used Landsat, ASTER, and Sentinel satellites images to interpret structures, soils and rocks. For data verification, the hyper-spectral systems USB 2000 and NIRQUEST 512.2 of Ocean Optics Inc. are used in laboratory and field spectrometric measurements. They make it possible to define the finest spectral characteristics of soil minerals and rocks for their identification. The obtained spectral data are compared with similar data from different instruments for Earth observation included in the spectral libraries. They correspond to the shape of the spectral signature in the same spectral range obtained with other spectrometers. These promising results encourage us to plan the next campaigns for the field spectroscopy measurements in different regions of Bulgaria.

Keywords: remote sensing, in-situ spectrometric measurements, spectral data, Earth observation, data verification

**ХИПЕРСПЕКТРАЛНИ ИЗМЕРВАНИЯ НА СКАЛИ И ПОЧВИ В ЦЕНТРАЛНО СРЕДНОГОРИЕ**

***Деница Борисова[1], Бануш Банушев[2], Христо Николов[1], Румен Недков [1], Даниела Аветисян[1]***

*[1]Институт за космически изследвания и технологии, Българска академия на науките, 1113 София; dborisova@stil.bas.bg*
*[2]Минно-геоложки университет "Св. Иван Рилски", 1700 София; banushev@mgu.bg*

**РЕЗЮМЕ**. Дистанционните изследвания са техника за получаване, обработка и интерпретация на изображения и многоканални спектрални данни, придобити от оптични сензори, монтирани на самолети и сателитни платформи, които регистрират взаимодействието между изследваните обекти и електромагнитната енергия. Приложението на дистанционните изследвания в наблюдението на Земята започва с проектирането и разработването на оборудване за извършване на изследванията на наблюдаваните обекти от разстояние и без да се нарушава тяхната цялост. Наземните данни са много важни при наблюдението на Земята. В тази работа изображенията от дистанционните наблюдения се използват в различни приложения - за проучване на минерални ресурси, за геоложки картографиране и за разпознаване на почвите и скалите чрез техните спектрални характеристики. Използвани са спътникови изображения от ресурните спътници Landsat, ASTER и Sentinel, с цел разпознаване на скални разкрития и почви. За проверка на данните са използвани спектрометричните системи USB 2000 и NIRQUEST 512.2 на Ocean Optics Inc., чрез които са проведени лабораторни и полеви спектрометрични измервания. Те осигуряват определянето на най-добрите спектрални характеристики на минералите в почвите и на скалите, които да послужат за разпознаването им при интерпретацията на спътниковите изображения. Получените спектрални данни се сравняват с подобни данни от различни инструменти за наблюдение на Земята, включени в спектрални библиотеки. Те съответстват на формата на спектралните характеристики в същия спектрален диапазон, получен с други спектрометри. Тези обещаващи резултати ни насърчават да планираме следващите кампании за полеви спектрометрични измервания в различни региони на България.

**Ключови думи**: дистанционни изследвания, in-situ спектрометрични измервания, спектрални данни, наблюдения на Земята, верификация на данни

## Introduction

Ground-truth data in Earth observation of the environment and in the remote sensing investigations are very important. Remote sensing images are used in the present paper for supporting mineral exploration and mapping geology and for recognizing soils and rocks by their spectral signatures. We used ASTER, Landsat, and Sentinel satellites images for interpreting both, rocks and soils. For data verification, the hyper-spectral systems USB 2000 and NIRQUEST 512.2 of Ocean Optics Inc. are applied for in-situ (laboratory and field) spectrometric measurements. They provide spectral data for defining the finest spectral characteristics of soil minerals and rocks for their identification. The obtained spectral data are compared with similar data from different instruments for Earth observation included in the spectral libraries, such as USGS and JPL data base. They correspond to the shape of the spectral signature in the same spectral range obtained with other spectrometers. These promising results encourage us to plan the next campaigns for collecting mineral, rock, and soil samples for the laboratory and for the field spectrometric measurements in different regions of Bulgaria.

## MATERIALS AND METHODS

### Landsat 8 Operational Land Imager

Landsat 8 Operational Land Imager (OLI) images consist of nine spectral bands with a spatial resolution of 30 meters for Bands 1 to 7 and 9. The ultra blue Band 1 is useful for coastal and aerosol studies. Band 9 is useful for cirrus cloud detection. The resolution for Band 8 (panchromatic) is 15 meters. The approximate scene size is 170 km north-south by 183 km east-west (106 mi by 114 mi) (https://landsat.usgs.gov/what-are-band-designations-landsat-satellites, July 2017).

### ASTER Instrument

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is an imaging instrument onboard Terra, the satellite of NASA's Earth Observing System (EOS) launched in December 1999. ASTER is a cooperative effort between NASA, Japan's Ministry of Economy, Trade and Industry (METI), and Japan Space Systems (J-spacesystems). ASTER data is used to create detailed maps of land surface temperature, reflectance, and elevation. The coordinated system of EOS satellites, including Terra, is a major component of NASA's Science Mission Directorate and the Earth Science Division. The goal of NASA Earth Science is to develop a scientific understanding of the Earth as an integrated system, its response to change, and to better predict variability and trends in climate, weather, and natural hazards (http://asterweb.jpl.nasa.gov/index.asp, July 2017).

The ASTER instrument consists of three separate instrument subsystems. Each subsystem operates in a different spectral region, has its own telescope(s), and was built by a different Japanese company. ASTER's three subsystems are: the Visible and Near Infrared (VNIR), the Shortwave Infrared (SWIR), and the Thermal Infrared (TIR). In our study, were used data from the subsystem in the SWIR region.

### SENTINEL-2 Multispectral Instrument

The Sentinel-2 Multispectral Instrument (MSI) will sample 13 spectral bands: four bands at 10 metres, six bands at 20 meters, and three bands at 60-meter spatial resolution. The acquired data, mission coverage and high revisit frequency provides for the generation of geo-information at local, regional, national, and international scales. The data is designed to be modified and adapted by users interested in thematic areas (https://earth.esa.int/web/sentinel/user-guides/sentinel-2-msi/overview, July 2017).

### Instruments Characteristics

The ASTER bands are overlaid on the atmosphere model presented on Figure 1.

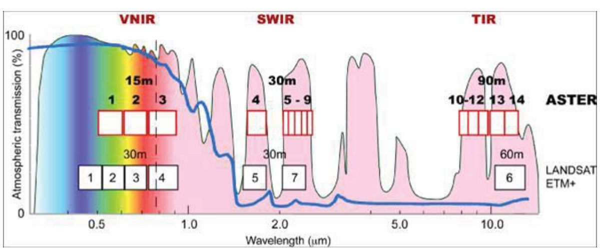



Fig. 1. ASTER bands (http://asterweb.jpl.nasa.gov/images/spectrum.jpg, July 2017)

SENTINEL-2 data is complementary to existing missions including LANDSAT (Fig. 2) and SPOT.

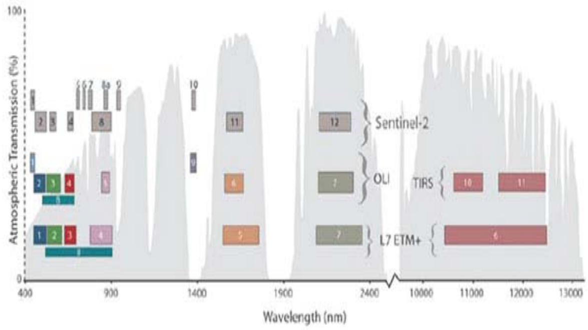



Fig. 2. Sentinel-2 and Landsat spectral bands (https://earth.esa.int/web/sentinel/user-guides/sentinel-2-msi/overview, July 2017)

### Field and laboratory instruments

For data verification, the hyper-spectral systems USB 2000 (TOMS) and NIRQuest 512.2 of Ocean Optics Inc. are used in the field and the laboratory (in-situ) spectrometric measurements. The field reflectance spectral signatures were obtained with a TOMS (Thematically Oriented Multi-channel Spectrometer) designed and constructed in the Remote Sensing System Department at the Space Research and Technology Institute – Bulgarian Academy of Sciences in collaboration with Alabama State University USA (Petkov et al., 2005). A high-performance optical bench, low-noise electronics, and various grating options make NIRQuest Spectrometers the best choice for modular NIR spectroscopy. This small footprint spectrometer is available in several different models that cover various wavelength ranges between 900 nm and 2500 nm. As with most Ocean Optics designs, the NIRQuest can be customized for your specific application with various grating, slit and mirror options. The NIRQuest is ideal for applications ranging from analyzing moisture content in food and beverage products to analyzing trace metals in wastewater and laser characterization among others. The NIRQuest 512.2 was used in the laboratory spectrometric measurements (https://oceanoptics.com/wp-content/uploads/OEM-Data-Sheet-NIRQuest.pdf, July 2017).

### ASTER Spectral Library

The ASTER spectral library includes data from three other spectral libraries: the Johns Hopkins University (JHU) Spectral Library, the Jet Propulsion Laboratory (JPL) Spectral Library, and the United States Geological Survey (USGS - Reston) Spectral Library.

In the present study, we used data from the ASTER spectral library for comparing the obtained infrared spectral data from ASTER instrument onboard of the airborne platform and the same data from laboratory measurements for the same rock samples included in the spectral libraries (Baldridge et al., 2009).

### Region of Interest (RoI)

The total area of the said region is about 600 km$^2$ located in the central part of Bulgaria. In this work, the region of interest is Central Srednogorie (Fig. 3). This zone is located in the central part of Bulgaria and belongs to Apuseni-Banat-Timok-

Srednogorie belt, into which one of Europe's richest porphyry Cu and Cu-Au epithermal deposits are located (Strashimirov et al., 2002; Popov et al., 2012). In the Srednogorie zone, situated 60-90 km east of Sofia, the ore deposits exploited contain mainly Cu and Cu-Au-Mo. In this region, 150 ore deposits, ore occurrences and mineral indications are found and documented.


Fig. 3. Metallogenic zones in Bulgaria (after Bogdanov, 1982; Bird et al., 2010)

About 10 km south of the town of Zlatitsa, on the road to Panagyurishte, an outcrop of the South Bulgarian granitoids are embedded in metamorphic rocks of the Proto-Rhodope group. To the South, Bulgarian granitoids intrusive bodies concerned with Palaeozoic ages, different sizes and composition, are divided into three intrusive complexes. The first set includes intrusive granites, grano-diorites, and small bodies of diorite and quartz-diorites. The Smilovene, Hissar and Poibrene plutons are included in this complex. The composition of the second intrusive complex includes amphibole-biotite, biotite, and light granites. The Koprivshtitsa, Klissura, and Matenitsa plutons belong to this complex. The third intrusive complex is represented by granular biotite, biotite-muscovite, and pegmatite granitoids. In this complex, the Strelcha, Karavelovo, Lesichovo, and Varshilo plutons are presented (Dabovski et al., 1972). In the point of field measurement, biotite granites of the Northwest Koprivshtitsa pluton are revealed. They are light gray, sometimes rusty colored by iron hydroxides, medium- to coarse-grained, with a clear lineal porphyroid parallelism. They are formed by K-feldspar, plagioclase, quartz, biotite, apatite, and zircon (Banushev et al., 2012).

## Results and Discussion

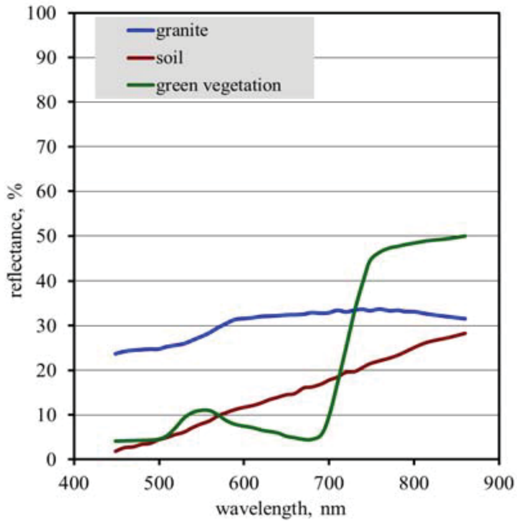
### Reference spectra

Reference spectra of granites, grano-diorites, and related soil types were obtained from the USGS and JPL spectral libraries. The USGS spectral library contains reference spectra for rocks and soils that represent different localities around the world but most of them are presented in one particle size (Clark et al., 2007).

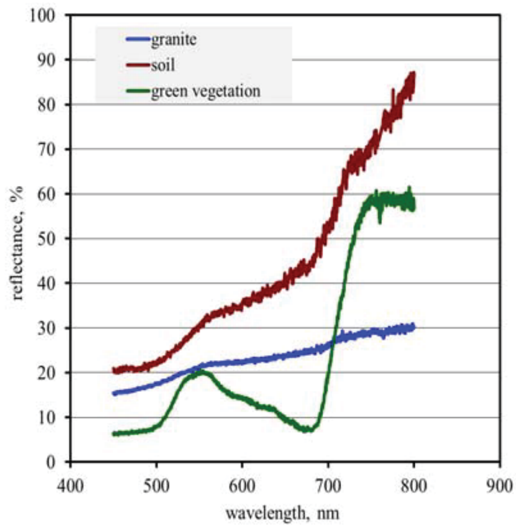
### Spectral analysis

According to specific features of the spectral signatures, the USGS and JPL reference spectra of granites, grano-diorites, and related soil types that are closest to granites, grano-diorites and related soil types in the RoI were analyzed.

In Figure 4a, the spectral reflectance signatures of granite (blue line reflects 23-33%), brown soils (brown line reflects 2-29%), and grass as green vegetation (green line typical reflective maximum at 0.55 $\mu m$ and (0.76-0.85) $\mu m$ and at least 0.67 $\mu m$) taken from the USGS spectral library (Baldridge et al., 2009) are presented. They represent reference spectral reflectance characteristics and are used for comparative interpretation of the results acquired during the field hyper-spectral measurements.




(a)

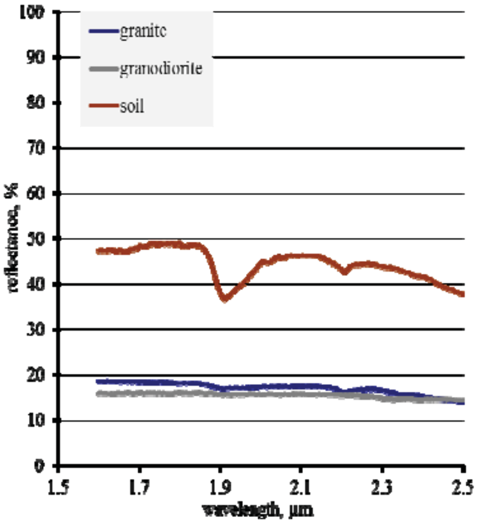



(b)

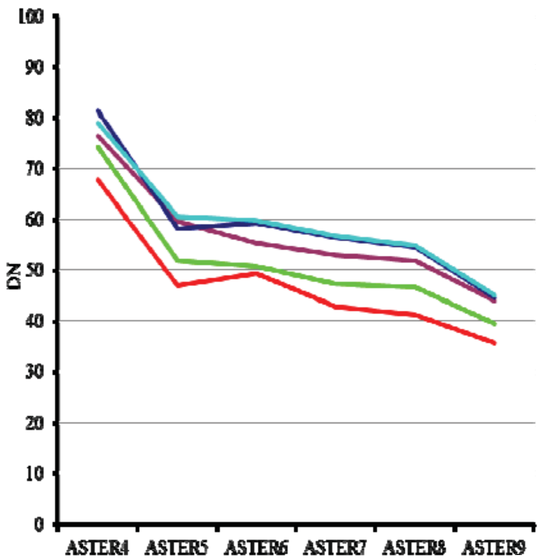
Fig. 4. Plot of spectral reflectance signatures of granites, related soil types and green vegetation obtained from: (a) ASTER reference library (Baldridge et al., 2009) and (b) TOMS field hyper-spectral measurements

Figure 4b shows the spectral reflectance characteristics of granite, brown forest soil, and green vegetation obtained in the field hyper-spectral measurements using the TOMS spectrometric system. The reflectance spectra of granites and brown forest soil show significant differences in value range (0.6-0.8) $\mu m$.

The infrared spectra of granite have increased water vapor, which causes a observable saw tooth appearance in the short wavelength region of the spectra (2-3) $\mu m$. Results show that it has an absorption feature around 1.9 $\mu m$ (Fig. 5). The 1.9 $\mu m$ feature is covered by atmospheric (water) absorption (Curran et al., 2001). This minimum in the spectral characteristics could be found in laboratory spectral data because of the higher amount of energy reaching the instrument detector.




(a)

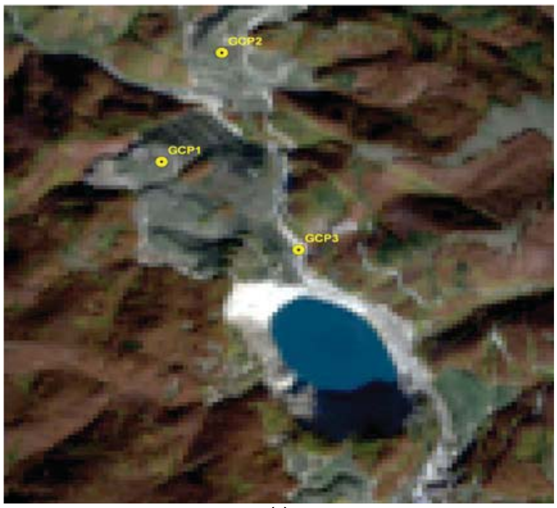



(b)

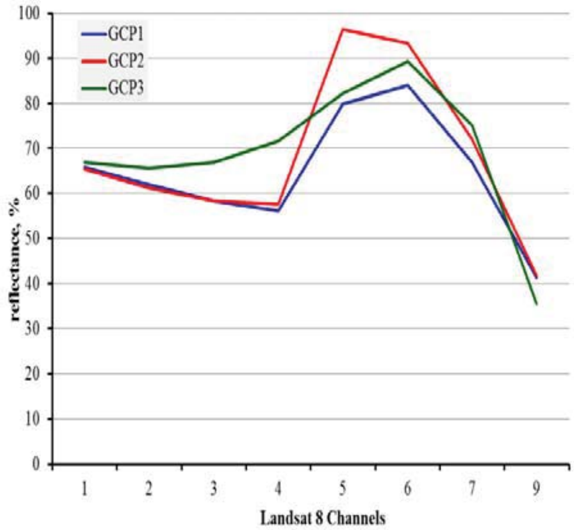
Fig. 5. Plots of infrared spectra of: (a) granites, grano-diorites, and related soil from ASTER library (Baldridge et al., 2009); (b) RoI from ASTER instrument

The ASTER spectra of exposed granites in RoI (green line in Figure 5) have the same trend as reference spectra from the spectral library. Since there are no detectors in the spectral range (1.8-2.1) $\mu m$, the missing spectral data could be the cause for misinterpretation of the infrared spectral data. Therefore, additional in-situ laboratory and field spectrometric measurements in this spectral range have to be planned and performed.

Figure 6a presents a Landsat 8 image (November 2015) of the RoI with three ground control points /GCPs/ for studied land covers. The GCPs include soil and rocks. Figure 6b demonstrates the spectral reflectance curves for each GCP obtained from Landsat 8. For better interpretation and classification of soils and rocks in mountain regions, the described measurements complete the methodologies explained in Avetisyan (2015) and Avetisyan and Nedkov (2015).



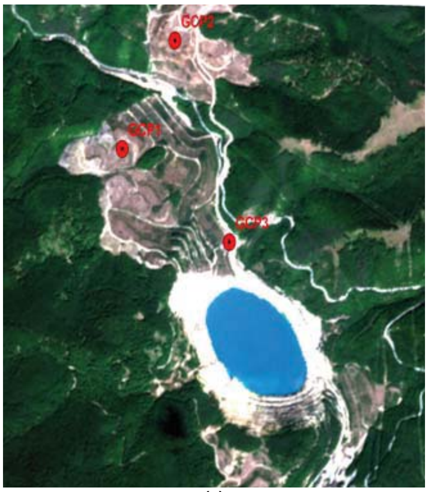

(a)



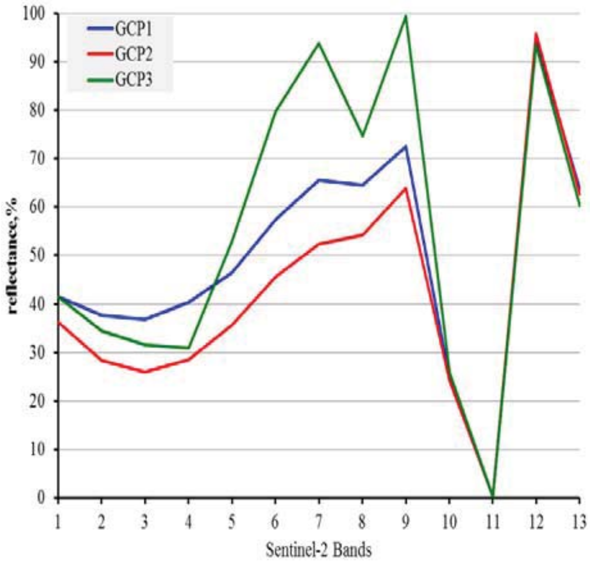

(b)

Fig. 6. Landsat 8 image of the RoI in 2015 with GCPs (1-3) (a) and relating spectral signatures (b)

A Sentinel-2 MSI image (August 2015) of the RoI with three ground control points /GCPs/ for studied land covers that are identical as those on Landsat 8 image is presented in Figure 7a. GCP1 and GCP2 include mainly soil and rocks. In GCP3, the three main land cover types – rocks, soils, and vegetation – are included. Figure 7b demonstrates the spectral reflectance curves for each GCP obtained from Sentinel-2 MSI.




(a)




(b)

Fig. 7. Sentinel-2 MSI image of the RoI in 2015 with GCPs (1-3) (a) and relating spectral signatures (b)

## Conclusions

Multispectral data from three different spectrometric systems – ASTER on satellite Terra, OLI on satellite Landsat 8, and MSI on satellite Sentinel-2 - were used in this study to identify exposed rocks and soils in the Central Srednogorie region, Bulgaria. For data verification, the hyper-spectral systems TOMS (USB 2000) and NIRQuest 512.2 of Ocean Optics Inc. were used in performing in-situ (the laboratory and the field) spectrometric measurements. The results show that the suggested methods for analyzing the spectral data could be useful for identifying exposed rocks and soils. Theoretical and analytical techniques that have been developed for the analysis of the laboratory spectral data were also applied to field spectral data. The shape of the spectral curves acquired during the laboratory and the field measurements confirmed this promising technique in satellite data verification.

## References

Банушев, Б., С. Приставова, Р. Костов, Р. Паздерав, Н. Цанкова, Е. Раева, С. Малинова. Ръководство за учебни практики по минералогия и петрография. ИК "Св. Иван Рилски", София, 2012. (Banushev, B., S. Pristavova, R. Kostov, R. Pazderav, N. Tsankova, E. Raeva, S. Malinova. Rakovodstvo za uchebni praktiki po mineralogiya i petrografiya. IK "Sv. Ivan Rilski", Sofia, 2012)

Дабовски, Х., И. Загорчев, М. Русева, Д. Чунев. Палеозойски гранитоиди в Същинска Средна гора. Год. УГП, 16, 1972. - 57-92. (Dabovski, H., I. Zagorchev, M. Ruseva, D. Chunev. Paleozojski granitoidi v Sashtinska Sredna gora. God. UGP, 16, 1972. - 57-92.)

Попов, П., С. Страшимиров, К. Попов, М. Каназирски, К. Богданов, Р. Радичев, С. Димовски, С. Стойков. Геология и металогения на Панагюрския руден район. София, Изд. къща „Св. Ив. Рилски", 2012. – 227стр (Popov, P., S. Strashimirov, K. Popov, M. Kanazirski, K. Bogdanov, R. Radichev, S. Dimovski, S. Stoykov. Geologiya i metallogeniya na Panagyurskiya ruden rayon. Sofia, Izd.kashta "St. Ivan Rilski", 2012. – 227p.)

Avetisyan, D. Assessment of vegetation cover degradation and soil erosion in Chuprene Reserve (Northwestern Bulgaria) using remote sensing and geographical information systems. Ecological Engineering and Environment Protection, 1, 2015. – 47-56.

Avetisyan, D., R. Nedkov. Determining the magnitude and direction of land cover changes in the semi-natural areas of Haskovo Region, Southeast Bulgaria. – Geoscience and Remote Sensing Symposium 2015, IEEE International, 2015. – 4637-4640.

Baldridge, A. M., S. J. Hook, C. I. Grove and G. Rivera. The ASTER Spectral Library Version 2.0. – Remote Sensing of Environment, 113, 2009. – 711-715.

Bird, G., P. Brewer, M. Macklin, M. Nikolova, T. Kotsev, M. Mollov, C. Swain. Dispersal of contaminant metals in the mining-affected Danube and Maritsa drainage basins, Bulgaria, Eastern Europe. – Water Air and Soil Pollution, 206 (1-4), 2010. – 105-127.

Bogdanov, B. Bulgaria. – In: Mineral Deposits of Europe. Vol.2. Southeast Europe (Eds. Dunning, F., W. Mykura, D. Slater). The Mineralog. Society, London, 1982. – 215-232.

Curran, P.J., J.L. Dungan, D.L. Peterson. Estimating the foliar biochemical concentration of leaves with reflectance spectrometry testing the Kokaly and Clark methodologies. - Remote Sens. Environ. 76, 2001. – 349-359.

Petkov, D., H. Nikolov, G. Georgiev. Thematically Oriented Multichannel Spectrometer (TOMS). – Aerospace Res. in Bulgaria, 20, 2005. – 51-54.

Strashimirov, S., R. Petrunov, M. Kanazirski. Porphyry-copper mineralisation in the central Srednogorie zone, Bulgaria. – Mineralium Deposita, 37, 2002. – 587-598.

http://asterweb.jpl.nasa.gov/index.asp, July 2017

http://asterweb.jpl.nasa.gov/images/spectrum.jpg, July 2017

https://earth.esa.int/web/sentinel/user-guides/sentinel-2-msi/overview, July 2017

https://landsat.usgs.gov/what-are-band-designations-landsat-satellites, July 2017

https://oceanoptics.com/wp-content/uploads/OEM-Data-Sheet-NIRQuest.pdf, July 2017

The article is reviewed by Prof. Stefan Dimovski, DSci. and Assist. Prof. Dr. Hristiyan Tsankov